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# A re-evaluation of the Type D personality effect

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## ABSTRACT

**Objective:** Type D personality has been associated with various medical and psychosocial outcomes. Type D's underlying personality traits negative affectivity (NA) and social inhibition (SI) are hypothesized to either additively (NA + SI) or synergistically (NA \* SI) affect an outcome. As some of the methods used to assess a Type D effect have been criticized in the past, this study aimed to investigate for all commonly used methods their tendency of producing false positive Type D effect.

**Method:** 324,000 datasets were generated using a Monte Carlo Simulation. Each dataset was analyzed using various methods to assess a Type D effect. Each method's performance was assessed in terms of absolute bias and the percentage of false positive findings. An online application was developed where readers can easily experiment with this simulation.

**Results:** Our simulation showed that all commonly used methods risk producing false positive Type D effects. The only method with adequate false positive rates included the continuous NA and SI main effects, as well as their quadratic effects and their interaction.

**Conclusion:** All commonly used methods to assess a Type D personality effect showed inflated false positive rates in realistic simulation scenarios. All earlier research based only on these methods should be reconsidered.

## 1. Introduction

The construct Type D ("distressed") personality (Denollet et al., 1996; Denollet, Sys, & Brutsaert, 1995) is characterized by the combination of its two subcomponents negative affectivity (NA) and social inhibition (SI). Negative affectivity represents the tendency to experience negative thoughts, emotions and behaviors, while social inhibition refers to the difficulty in expressing thoughts and emotions, particularly in a social context. The combined presence of these traits is called Type D personality and has been linked to various medical and psychosocial outcomes, such as an increased risk of cardiac events (for a meta-analysis, see Grande, Romppel, & Barth, 2012) or poor medication adherence (Williams, O'Connor, Grubb, & O'Carroll, 2011). Type D theory states that the combined influence of NA and SI is essential, because the combination of experiencing emotional distress and not being able to express these feelings is especially stressful to individuals and may result in serious health problems (Denollet et al., 1995).

Considerable debate exists on how to statistically model this combined influence of two personality traits. Commonly used methods

classify people in personality subgroups based on whether they score above or below a particular cut-off on the continuous NA and SI traits. Such subgroup approaches should result in Type D effects when both NA and SI are important in explaining an outcome, but various authors have argued that these approaches may falsely result in Type D effects when only one of the Type D personality traits is related to the outcome (Ferguson et al., 2009; Smith, 2011). Lodder (2020) provided the first empirical support of this criticism by showing that these methods produce Type D personality effects even if only one of the personality traits (NA or SI) is related to the outcome. The last decade, researchers have started to estimate Type D personality effects based on the main and interaction effects of the continuous NA and SI scores. However, in this article we argue that even such continuous analyses risk producing false positive Type D effects when the regression model is not correctly specified. This conclusion is substantiated by a computer simulation, where we have generated a wide variety of empirically plausible datasets and have compare the performance of various commonly used methods in estimating a Type D effect.

**Abbreviations:** NA, negative affectivity; SI, social inhibition

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### 1.1. Commonly used methods

Although latent variable methods are arguably preferred when modeling constructs measured with error such as psychological questionnaire scores (Lodder et al., 2019), the present article focuses on methods that directly model the observed scores, as these are almost always used in the Type D literature. What the commonly used Type D operationalizations have in common is that they use the DS-14 questionnaire (Denollet, 2005) to measure Type D's subcomponents NA and SI, both measured with seven items on a 0–4 Likert scale. These two sets of seven items are then summed to get the NA and SI sum scores. From that point onward the methods start to diverge.

#### 1.1.1. 2-Group method

The 2-group method is most commonly used and classifies persons as “Type D” when they score higher than the predetermined cutoff of 10 on both the NA and SI sum scores. All other people are classified as “Not Type D”. The resulting binary/dichotomous variable is subsequently used as an independent variable in statistical analyses to investigate its association with some outcome. For an example of this method see Denollet (2005). This approach resonates with the idea that people need to score high enough on both underlying NA and SI traits (i.e. above the cut-off) before their personality can start to negatively influence various aspects of people's life (Denollet, 2005).

#### 1.1.2. 4-Group method

The 4-group method is similar to the 2-group method, but further classifies the “Not Type D” people in three categories based on whether they score higher or lower than the cutoff of 10 on the NA and SI sum scores: “NA + SI –”, “NA – SI +”, “NA – SI –”. As this method classifies people in 4 groups, using this variable in regression analyses requires transforming this 4-group variable into three dummy variables that indicate whether people belong to the Type D group (NA + SI +), the High NA group (NA + SI –) or the High SI group (NA – SI +). Using these three dummy variables as predictors in regression analyses by default causes the remaining fourth group (NA – SI –) to become the reference group. The effects of the three other groups are thus expressed relative to this reference group. Knowing whether the Type D group differs from the High NA or High SI groups requires a slightly different dummy coding. Using the 4-group method to conclude a Type D effect requires three separate tests to be statistically significant. Strictly speaking, the Type D group should not only differ significantly from the reference group, but also from the High NA and High SI groups, as this would show the added value of scoring high on both personality traits. For an example of this method see Nefs et al. (2015).

**1.1.2.1. Limitations of subgroup methods.** The 2-group and 4-group methods have been criticized by various scholars for several reasons (Ferguson et al., 2009; Lodder, 2020; Smith, 2011). First, by using a cutoff to classify people into high or low scores on NA and SI, these methods destroy valuable information on individual differences on these personality traits (Jaccard, Wan, & Turrissi, 1990; MacCallum, Zhang, Preacher, & Rucker, 2002; Maxwell & Delaney, 1993). Consequently, this categorization forces researchers to assume that the effect on an outcome is similar for every member of a subgroup. A second criticism of these methods is that the Type D effects are not only sensitive to true Type D effects (i.e. both NA and SI affect the outcome), but also result in significant effects when just one of the two traits is related to the outcome (Coyne & de Voogd, 2012; Smith, 2011). Consequently, these methods are not very specific in their conclusions. At most, they tell us that some aspect of Type D personality is related to the dependent measure, but they do not inform about the nature of the association (e.g. additive, quadratic, synergistic) or whether the Type D effect is caused by NA, SI, or both. A computer simulation study found support for this criticism, showing that subgroup methods resulted in significant Type D effects even when

only one of the Type D personality traits was related to the outcome (Lodder, 2020).

One could argue that such false positive Type D effects can be prevented by investigating the effect of the Type D group versus the three other groups using the 4-group method, because if only NA is related to the outcome, then surely the comparison between the Type D group and High NA group would be non-significant. Similarly, if only SI is related to the outcome, then the Type D group should not differ from the High SI group. However, we argue that this is not necessarily true when the two constructs involved in the classification are correlated, because dichotomizing two continuous correlated variables may cause spurious effects for one variable (e.g. SI) when only the other variable (e.g. NA) is related to an outcome (Maxwell & Delaney, 1993).

#### 1.1.3. Continuous method

To tackle the problems of these subgroup methods, several researchers have argued to use assess Type D effects using a *continuous method* (Ferguson et al., 2009; Lodder, 2020; Smith, 2011), using the continuous NA and SI sum scores as predictors in a regression analysis together with their interaction (i.e. the product of the mean-centered sum scores). When the NA and SI sum scores are both independently related to an outcome, there is an *additive Type D effect*. When the interaction between NA and SI is significant and in the same direction as the main effects, then there is a *synergistic Type D effect*, because the effect of the NA and SI traits is more than the sum of the two parts. Many researchers have argued that the Type D effect is more than the sum of its parts and therefore synergistic (Denollet et al., 1995; Denollet et al., 2006; Denollet, Pedersen, Vrints, & Conraads, 2013; Kupper & Denollet, 2007; Pedersen & Denollet, 2003). For instance, Kupper and Denollet (2007) explicitly stated that Type D personality is a synergy between NA and SI. Statistically, synergy can best be modeled in terms of a statistical interaction effect between the continuous scores of two constructs (Lodder, 2020). See Lodder et al. (2019) for an empirical application of the continuous method.

**1.1.3.1. Limitations of the continuous method.** However, we argue that this proposed continuous method is also not without problems. For this method to perform adequately, it is important that the model is correctly specified. Earlier research has shown that misspecification may result in misleading conclusions about the effects estimated in a statistical model. For instance, if researchers are interested in testing the interaction effect between NA and SI on a dependent measure, then they should also include the NA and SI main effects in the model (Aiken, West, & Reno, 1991). Not doing so may risk spurious interaction effects when only a main effect is underlying the data. Suppose that in reality only NA is related to the dependent measure, then multiplying the NA and SI sum scores will likely result in a significant effect for this interaction term when researchers do not adjust for the NA main effect. This is because the interaction term partly contains variance coming from NA, so the significance of the product score is confounded by the significance of the NA main effect. Although this problem can be significantly reduced by mean centering the NA and SI scores before multiplying them, in this article we show that even this approach results in bias. For recent examples of such misspecification in the Type D literature, see Dehghani (2018) or Smith et al. (2018).

Another misspecification in models testing interaction effects is not adjusting the model for quadratic effects. Various studies have shown that significant interaction effects can masquerade as an unmodeled non-linear (e.g. quadratic) effect of one of the constructs involved in the interaction, especially when the two constructs are correlated (Belzak & Bauer, 2019; Busemeyer & Jones, 1983; MacCallum et al., 2002). Let's suppose that (1) in reality NA and SI are correlated, (2) only NA has a quadratic effect on an outcome, and therefore (3) SI is not related to the outcome. These three requirements are sufficient in producing spurious interaction effects (i.e. spurious synergistic Type D effects).

But how plausible are these assumptions? First, NA and SI typically

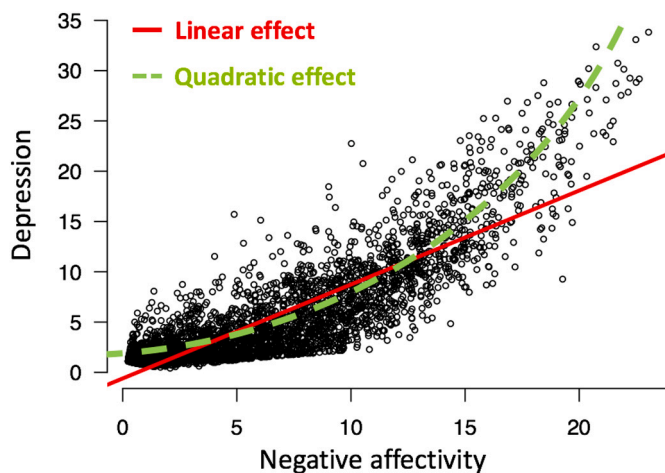


Fig. 1. Empirical data (based on Lodder et al., 2019) where a quadratic curve describes the association between NA and Depression better than a linear curve.

show a positive correlation around 0.5 (e.g. Ferguson et al., 2009; Grande, Romppel, Glaesmer, & Hermann-Lingen, 2010; Horwood, Anglim, & Tooley, 2015). Second, personality traits occasionally show quadratic relationships with other variables. For instance, quadratic relations have been found between neuroticism and depression (Jorm et al., 2000) and between conscientiousness and job performance (Whetzel, McDaniel, Yost, & Kim, 2010). More importantly, several studies have found quadratic effects for NA or SI on various outcome measures (Lodder et al., preprint; Kupper, Lodder, Habibovic, Spek & Denollet, preprint; Lodder et al., 2019). For instance, Fig. 1 illustrates that a quadratic curve described the association between NA and depression much better than a linear curve. Interestingly, not adjusting for the quadratic NA and SI effects resulted in a significant interaction between NA and SI (i.e. a synergistic Type D effect). However, this interaction was no longer significant when adjusting for the quadratic effects of NA and SI, suggesting that Type D was not synergistically related to depression and anxiety because this synergy was confounded by the presence of unmodeled quadratic effects. Nevertheless, given that *both* quadratic effects were significant in that study, one could still speak of an *additive quadratic* Type D effect. To sum up, misspecifying the continuous interaction model by either omitting the NA and SI main effects or quadratic effects may cause spurious synergistic Type D effects.

### 1.2. Inconsistent empirical findings

In the empirical literature, several studies have shown inconsistent results when estimating the Type D effect according to both the 2-group and continuous methods on the same dataset. For instance, Horwood, Anglim, and Tooley (2016) used the 2-group method to show that people with Type D personality have significantly more physical and psychological symptoms than people without Type D personality. However, the results of the continuous method indicated that these symptoms were only related to NA. Neither SI, nor the interaction between NA and SI was statistically significant. Similarly, Bouwens et al. (2019) used the 2-group method to indicate that vascular surgery patients with a Type D personality have a significantly lower quality of life than patients without a Type D personality. However, the result of the continuous method showed that only NA predicted a lower quality of life, not SI or the interaction between NA and SI. These inconsistencies suggest that conclusions regarding whether or not it is the combination of NA and SI that is important in explaining variation in the outcome, depend on the statistical model used to assess the Type D effect. This warrants investigating the performance of these methods using a computer simulation. Such simulation studies are useful tools for

discovering whether statistical models perform adequately under a wide variety of circumstances. By simulating datasets that closely match the patterns found in empirical data, simulation studies are not limited to investigating statistical issues (e.g. does a method produce biased effects?), but may also shed light on substantive issues (e.g. are previously reported Type D effects valid?).

### 1.3. The present study

The present study aims to investigate the performance of the 2-group, 4-group and the continuous interaction method in detecting Type D effects and effects of NA or SI only. The goal of this simulation was not so much to precisely assess the bias of each method under a wide variety of underlying effects (see Lodder (2020) for that purpose), but more to illustrate the misleading conclusions that could be drawn when assessing a Type D personality effects in specific circumstances. The simulation results reported below are therefore limited to several interesting combinations of input parameters. For reasons of simplicity, only those parameters were varied that illustrate how some methods can result in conclusions incongruent with the data generating model. The correlation between NA and SI was of special interest, as this correlation explains why some methods do not perform adequately.

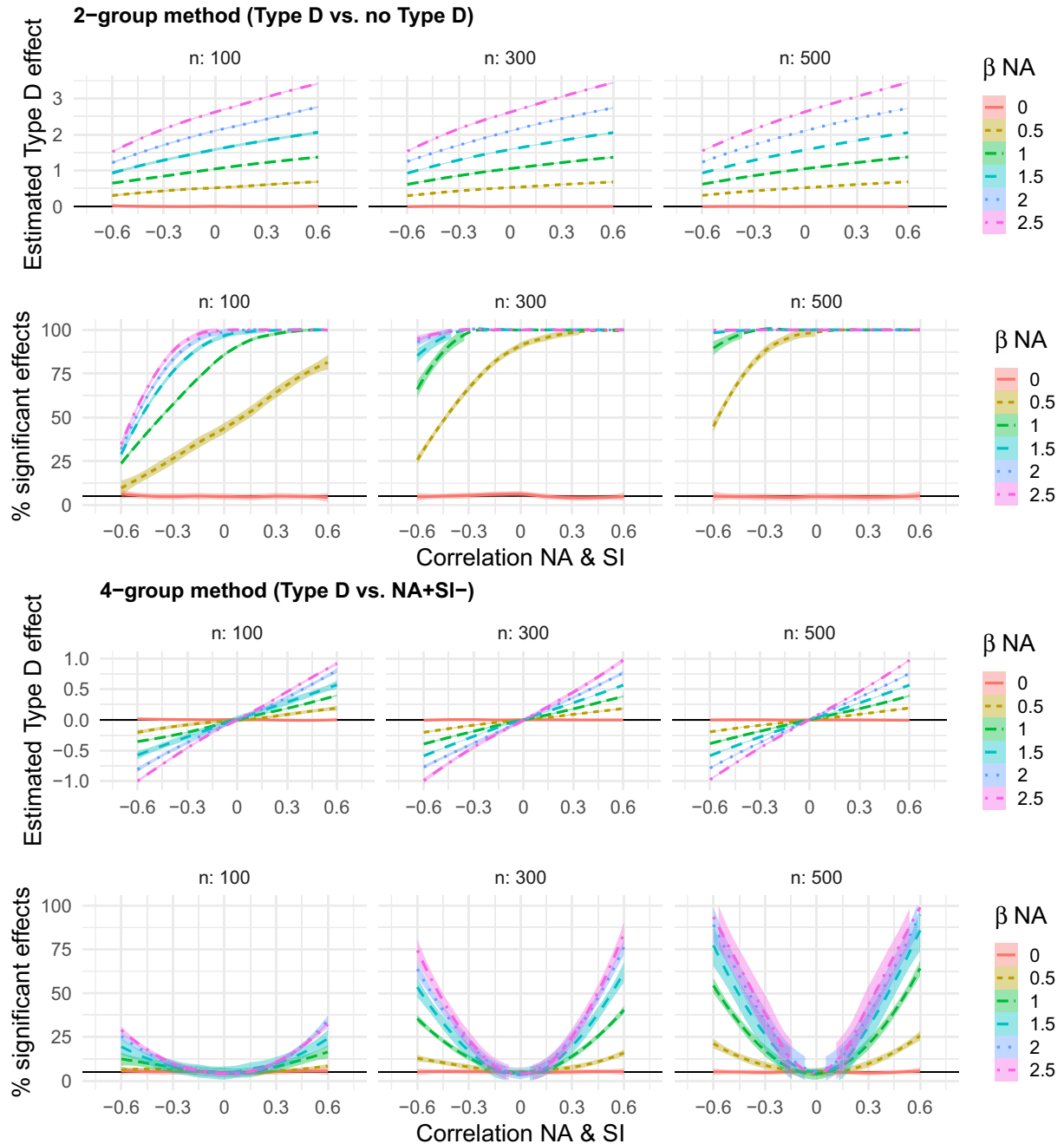
Based on earlier research (Lodder, 2020), we expect that the 2-group method will result in false positive Type D effects when only one of the underlying personality traits is related to the outcome. We expect similar false positive Type D effects for the continuous interaction method when the NA and SI main effects are not included in the model. We expect these two methods to be biased, regardless of the correlation between NA and SI. Contrarily, we expect the 4-group method to *only* produce false positive Type D effects when NA and SI are sufficiently correlated. Lastly, in line with Belzak and Bauer (2019), we expect that a positive correlation between NA and SI causes the continuous interaction model without the quadratic NA and SI effects to falsely detect a synergistic Type D effect (interaction between NA and SI) when only a quadratic NA or SI effect is underlying the data. Readers are encouraged to use the online app specially developed for the purpose of this article, to experiment with simulating different kinds of Type D effects.

## 2. Method

In this computer simulation, 324,000 datasets were generated to test the association between Type D personality and a continuous dependent measure. These simulated datasets varied across sample size ( $n = 100, 300, 500$ ), and the correlation between NA and SI ( $-0.60, -0.45, -0.30, -0.15, 0, 0.15, 0.30, 0.45, 0.60$ ). In the first simulation the size of the NA main effect (0, 0.5, 1.0, 1.5, 2.0, 2.5) was varied and in the second simulation the size of the NA quadratic effect (0, 0.1, 0.2, 0.3, 0.4, 0.5), comprising a total of  $162 + 162 = 324$  unique simulation conditions with 1000 datasets generated in each condition. The simulation R-scripts are available on this project's open science framework page (<https://osf.io/9ht35>). Readers can experiment with the simulation using a specially developed R-shiny application ([https://plodder.shinyapps.io/Type\\_D\\_effect\\_simulation/](https://plodder.shinyapps.io/Type_D_effect_simulation/)).

### 2.1. Data generation

In each generated dataset, the two vectors containing latent NA and SI scores were generated using  $n$  draws from a bivariate normal distribution ( $\mathbf{M} = [0, 0]$ ;  $\mathbf{SD} = [1, 1]$ ). The correlation between NA and SI varied across the simulation conditions. The scores on the continuous dependent measure were generated using a linear regression model with six parameters (formula 1): the intercept ( $\beta_0$ ), the main effects of NA ( $\beta_1$ ) and SI ( $\beta_2$ ), the interaction between NA and SI ( $\beta_3$ ), and the quadratic effects of NA ( $\beta_4$ ) and SI ( $\beta_5$ ). In the present simulations,  $\beta_0$ ,  $\beta_2$ ,  $\beta_3$ , and  $\beta_5$  were fixed to zero. The NA main effect ( $\beta_1$ ) and NA quadratic effect ( $\beta_4$ ) varied across simulation conditions.



**Fig. 2.** The estimated regression coefficients and proportion of significant effects of the 2-group method (upper two rows) and the 4-group method's contrast between the Type D group and the group with high NA scores only (bottom two rows). The simulated datasets varied across sample size (columns), the correlation between NA and SI (x-axis) and the true effect underlying the simulated data (NA main effect; separate lines). All other effects were fixed to zero.

$$Y = \beta_0 + \beta_1 NA + \beta_2 SI + \beta_3 (NA * SI) + \beta_4 NA^2 + \beta_5 SI^2 + e \quad (1)$$

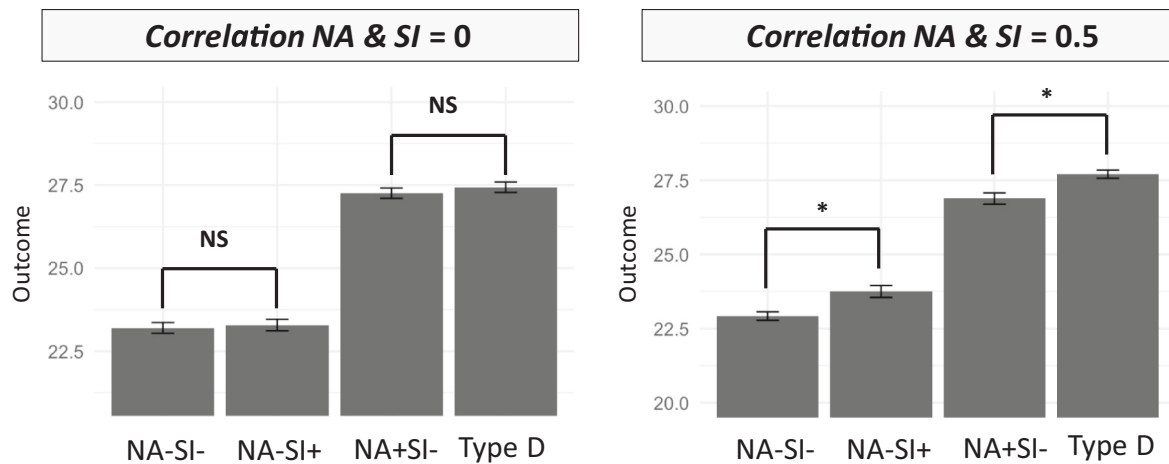
Subsequently, the latent NA and SI scores were transformed to DS14 item scores using a standard two-factor model with measurement model parameters based on a model fitted to empirical data (factor loadings ranging from 0.68 to 0.82, intercepts from  $-1.02$  to  $-0.78$ , and residuals from 0.33 to 0.54). Symmetric threshold parameters were used to transform the generated continuous NA and SI scores to ordinal score on a 0–4 Likert scale (Muthén & Kaplan, 1985). For both NA and SI, the ordinal item scores were summed and the resulting sum scores were used in further analyses.

## 2.2. Data analysis

Each simulated dataset was analyzed using six different linear regression analyses (two personality group analyses and four continuous analyses):

- (1) the 2-group method,
- (2) the 4-group method
- (3) Continuous method:  $NA * SI$  (without mean-centering NA and SI)
- (4) Continuous method:  $NA * SI$
- (5) Continuous method:  $NA * SI + NA + SI$
- (6) Continuous method:  $NA * SI + NA + SI + NA^2 + SI^2$





**Fig. 3.** For the 4-group method, the mean scores on a simulated outcome when only NA is related to this outcome. The correlation between NA and SI was simulated to be either 0 (left panel) or 0.5 (right panel).

NA – SI– = Reference group; NA – SI+ = Only high SI scores; NA + SI– = only high NA scores; NS = not significant.

\*  $p < .05$ .

For each method, the Type D effect was estimated according to the procedures described in the introduction. In each simulation condition, the 1000 estimated regression coefficients were averaged and the proportion significant effects was determined by dividing the total number of significant effects in a condition by 1000 (replications).

### 3. Results

Figs. 2 to 5 visualize the simulation results for the six regression analyses used to estimate a Type D effect. The next sections discuss the results for each method separately.

#### 3.1. 2-Group method

Fig. 2 visualizes the simulation results for data where *only* NA was linearly related to an outcome. The size of this NA main effect varied across conditions (separate lines), as did the sample size (figure columns) and the correlation between NA and SI (x-axis). The figure shows the estimated regression coefficients and proportion of significant effects of the 2-group method and the 4-group method's contrast between the Type D group and the group with high NA scores only. When only one personality trait is simulated to be related to the outcome, there is neither an additive (NA + SI) nor synergistic (NA \* SI) Type D personality effect. This implies that on average, the Type D effects should be equal to zero and the percentage of significant Type D effects should be equal to 5% (the false positive rate given the chosen significance level).

However, Fig. 2 shows that when only NA was related to the dependent measure, the 2-group approach almost always produced statistically significant Type D effects that followed the size of the NA main effect. These false positive rates increased alongside the correlation between NA and SI. The same patterns (not visualized) were observed when we simulated only SI to be related to the outcome. In line with our first expectation, this highlights the problem of the 2-group method: it results in significant effects even when only one of the Type D personality traits was related to the outcome.

#### 3.2. 4-Group method

Fig. 2 also shows that the 4-group method did also not perform adequately. When only NA, and not SI, was related to the outcome, then the Type D group should not differ from the High NA group, because these groups should score approximately equal on NA. However, the

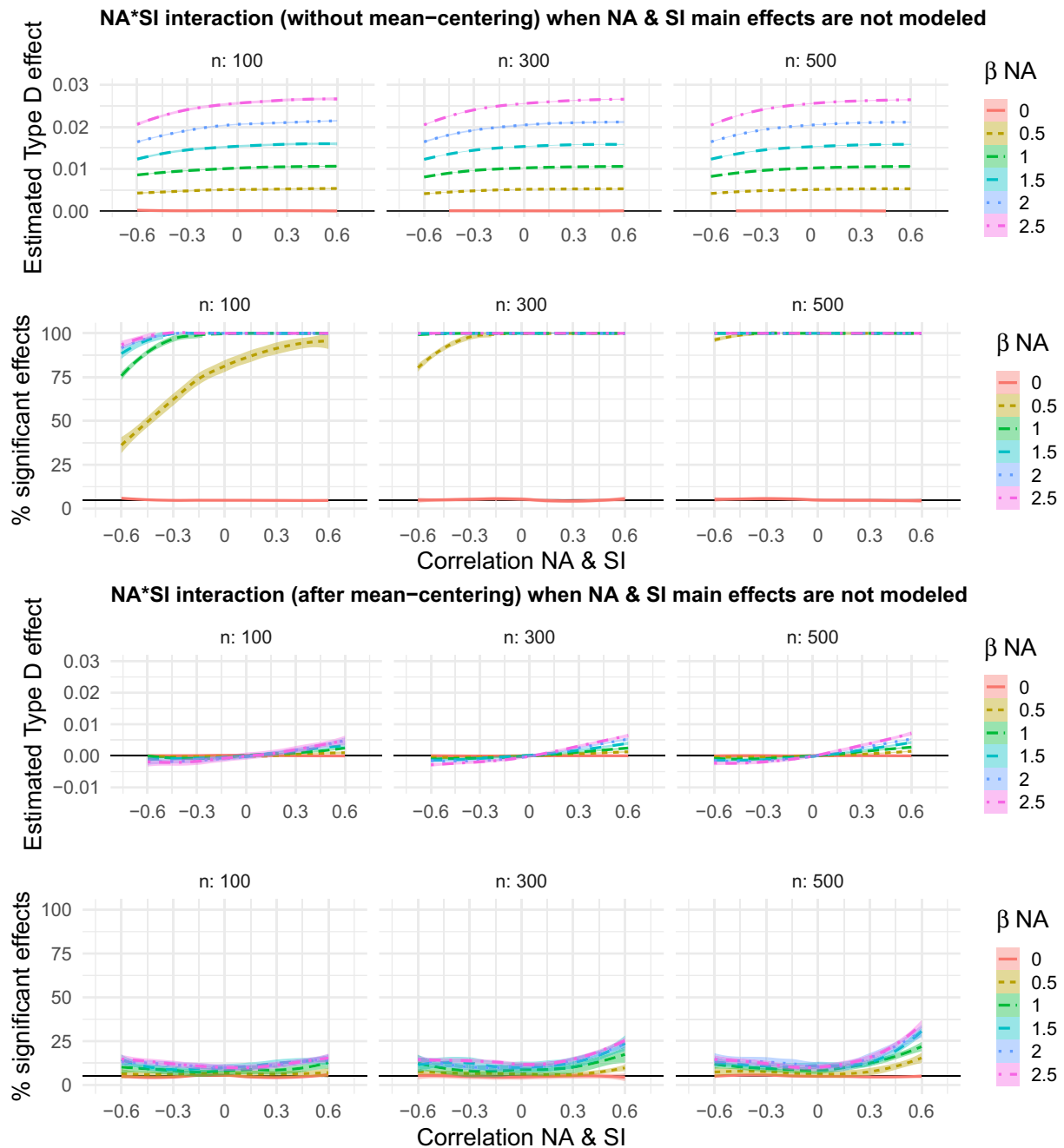
results indicate that the 4-group method produced false positive Type D effects as long as the correlation between NA and SI was unequal to zero. In line with our expectations, part of NA's effect spilled over to SI due to the correlation between NA and SI, resulting in false positive Type D effects. Fig. 3 further illustrates the role of the correlation between NA and SI in the bias of the 4-group approach. When only NA was related to the outcome, the scores in the NA + SI– and Type D groups were equal and differed significantly from both the NA – SI+ and NA – SI– groups. However, simulating a more realistic value for the correlation (0.5) resulted in an upward bias in the mean scores of the Type D group and the NA – SI+ groups, because some of NA's effect spilled over the SI due to the positive correlation between these traits.

#### 3.3. Continuous interaction method without main effects

In Fig. 4 again *only* NA was linearly related to an outcome. The figure shows the simulation results for the continuous interaction model without the NA & SI main effects. In line with our expectations, such model misspecification resulted in significant interaction effects (synergistic Type D effect) when in reality only NA was related to the outcome (upper two rows). These false positive interaction effects could largely be prevented by first mean-centering the NA and SI sum scores before multiplying them. Although the bottom rows of Fig. 4 indicate that a mean-centered interaction term resulted in much lower false positive rates than the uncentered method, the rate was still higher than the nominal 5% rate when NA and SI were correlated. The unadjusted continuous method does therefore not perform adequately.

#### 3.4. Continuous interaction method without quadratic effects

Fig. 5 shows the estimated regression coefficients and proportion of significant effects for the continuous interaction method where only NA was quadratically related to the outcome and all other effects were fixed to zero. Each dataset was analyzed according to the continuous method including the main effects of NA and SI and their interaction. The NA and SI quadratic effects were modeled in the upper two rows but not in the bottom two rows. In line with our expectations, this figure illustrates that not modeling true quadratic effects produced spurious synergistic Type D effect (NA \* SI interaction). This bias increased alongside the correlation between NA and SI. Such interaction effects should not occur when only a quadratic NA effect is underlying the data. The second row of Fig. 5 illustrates the importance of including quadratic effects in the model: this kept the false positive rates



**Fig. 4.** The estimated regression coefficients and proportion of significant effects of the continuous interaction model without the NA & SI main effects. When computing the NA \* SI interaction term, mean-centering was applied in the bottom two rows but not in the upper two rows. The simulated datasets varied across sample size (columns), the correlation between NA and SI (x-axis) and the true effect underlying the simulated data (NA main effect; separate lines). All other effects were fixed to zero.

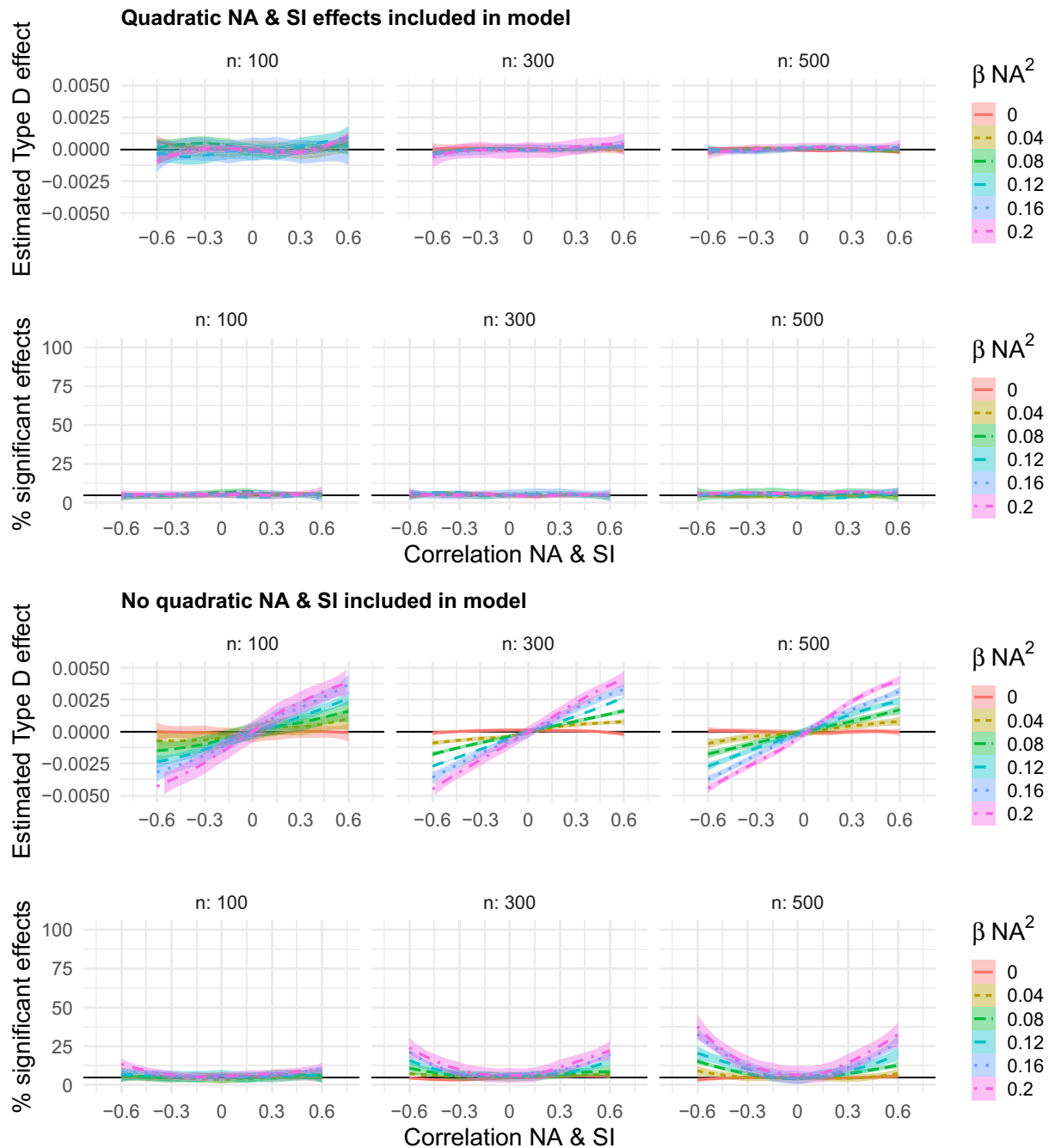
around 5% when no true NA \* SI interaction effect was present in the simulated data.

#### 4. Discussion

This study investigated the performance of various commonly used methods to assess a Type D personality effect. Our results corroborate the earlier finding (Lodder, 2020) that the 2-group method is sensitive to any kind of underlying NA and SI effect. Moreover, our findings indicate inflated false positive rates for the 4-group method and the misspecified continuous methods, given the realistic assumption that there is a positive correlation between NA and SI around 0.5 (e.g. Ferguson et al., 2009; Grande et al., 2010; Horwood et al., 2015). When

only one of these traits is related to an outcome, the positive correlation between the traits causes part of one trait's effect to spill over to the other trait, thereby falsely suggesting that both traits are related to the outcome. Although earlier studies have advocated to model the Type D effect as the continuous NA and SI scores and their interaction (Ferguson et al., 2009; Lodder, 2020; Smith, 2011), our study shows that even this approach may result in spurious interaction effects when not including the NA and SI main effects and quadratic effects in the model. Note that these cited authors did not advocate for constructing such misspecified regression models.

Table 1 summarizes the simulation results. For various underlying NA and SI effects in the population, it shows the expected results of sufficiently powered statistical tests of the 2-group, 4-group and



**Fig. 5.** The estimated regression coefficients and percentage of significant Type D personality effects (based on the continuous NA \* SI interaction effect). The simulated datasets varied across sample size (columns), the correlation between NA and SI (x-axis), and the true effect underlying the data (NA quadratic effect; separate lines). NA & SI quadratic effects were modeled in the upper two rows but not in the bottom two rows.

continuous methods, given that NA and SI are positively correlated. Based on the simulation results, we recommend to model Type D effects using the continuous method including the main, interaction and quadratic effects. This model can identify the presence of additive Type D effects (significant NA and SI main effects), additive quadratic Type D effects (significant NA and SI quadratic effects) or synergistic Type D effects (significant interaction between NA and SI). We encourage researchers to preregister the expected kind of Type D effect *before* analyzing the data, in order to prevent capitalizing on chance by conducting several statistical tests of the Type D effect.

Our findings suggest that some of the Type D effects reported in the literature may not be true Type D effects, but rather other types of NA

or SI effects. First, all reported synergistic Type D effects may in fact be spurious due to unmodeled quadratic NA and/or SI effects. Second, all reported synergistic Type D effects that were not adjusted for the NA and SI main effects, may in reality only represent a NA or SI main effect. Third, all significant Type D effects using the 2-group and 4-group methods may be effects of NA or SI only, even when the 4-group method indicates that the Type D group differs significantly from both the High NA and High SI groups.

It remains unclear how many published studies in the Type D literature have reported false positive Type D effects. It would therefore be interesting to know the percentage of studies where different methods to assess the Type D effect result in different conclusions.



**Table 1**

For various observed significant effects, the possible underlying effect(s) according to the 2-group, 4-group and continuous methods, given a positive correlation between NA and SI.

Observed significant effect	Underlying effect						
	NA	SI	NA + SI	NA * SI	NA <sup>2</sup>	SI <sup>2</sup>	NA <sup>2</sup> + SI <sup>2</sup>
2-Group method							
Type D effect	x	x	x	x	x	x	x
4-Group method							
Type D effect (vs. reference group)	x	x	x	x	x	x	x
Type D effect (vs. high NA group)	x	x	x	x	x	x	x
Type D effect (vs. high SI group)	x	x	x	x	x	x	x
Continuous method (excluding quadratic effects)							
NA	x						
SI		x					
NA + SI (additive Type D effect)			x				x
NA * SI (synergistic Type D effect)				x	x	x	x
Continuous method (including quadratic effects)							
NA	x						
SI		x					
NA + SI (additive Type D effect)			x				
NA * SI (synergistic Type D effect)				x			
NA <sup>2</sup>					x		
SI <sup>2</sup>						x	
NA <sup>2</sup> + SI <sup>2</sup> (additive quadratic Type D effect)							x

NA = negative affectivity; SI = social inhibition.

Future research could for instance investigate the discrepancy between the 2-group and continuous method, in the subset of studies that reported the results according to both methods (e.g. Bouwens et al., 2019; Horwood et al., 2016).

Another way to assess the potential bias in the Type D literature would be to conduct individual patient data meta-analyses (Riley, Lambert, & Abo-Zaid, 2010) on commonly investigated dependent measures. This allows for a sufficiently powered test of the Type D effect using a correctly specified continuous method. A first attempt to conduct such an analysis has already been initiated, focusing on the association between Type D personality and adverse (cardiac) events in patients with coronary heart disease (Lodder, Wicherts, Denollet, & Kupper, preregistration).

In the R-shiny application, the NA and SI scores were not generated from a latent variable model and were assumed to be perfectly reliable, in order to reduce the application's computation time. Consequently, the effects estimated by the app are not attenuated, as typically seen when analyzing imperfectly reliable measures using their observed score methods rather than latent variable methods (Spearman, 1904). Nevertheless, the simulated datasets in this study were generated according to a latent variable method and the conclusions regarding the bias of the Type D methods are similar to those resulting from the app.

In sum, this study indicated that all methods commonly used to assess a Type D personality effect showed inflated false positive rates in empirically plausible simulation scenarios. The least biased method to assess the Type D effect (be it additive or synergistic) does not only model the continuous NA and SI main effects and their interaction, but also adjusts for the NA and SI quadratic effects. Our findings suggest that some Type D effects reported in the literature are not true Type D effects, but rather other types of NA or SI effects. To shed more light on the extent of this problem, we recommend that earlier published studies investigating a Type D effect should be reanalyzed using the continuous interaction method including the quadratic NA and SI effects. Our conclusions are not limited to research on Type D personality, but any field where two continuous measures are transformed in either 2 or 4 groups based on some cutoff risks falsely concluding a combined effect for these measures.

## CRediT authorship contribution statement

**Paul Lodder:** Conceptualization, Methodology, Software, Formal analysis, Visualization, Writing - original draft.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.paid.2020.110254>.

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